Optimization of Skidding Distances in Mountain Conditions with Different Skidding Devices

Zdravko Trajanov, Ljupcho Nestorovski, Pande Trajkov

Abstract – Nacrtak

In forestry practice, during forest harvesting there are many different situations while skidding timber assortments, which are dealt with individually depending on the circumstances.

The main purpose of this scientific paper is to offer a model for the calculation of the optimal distance for skidding timber assortments uphill or downhill, in mountain conditions. The working area i.e. the harvesting volume is situated between two storey (horizontal) forest roads. This solution would enable the forest experts to make the right decisions when planning timber assortment skidding, i.e. to achieve the most favorable financial results of the work.

The method is based on work efficiency i.e. the time required for skidding certain timber assortments (logs and firewood), when skidding is done by animals, adapted tractor equipped with winch, and mobile cable crane.

Keywords: skidding, timber assortments, optimal distance, uphill, downhill, logs and firewood

1. Introduction – *Uvod*

In practice, during forest harvesting, a goal is set in order to determine the methodology for skidding a certain volume of wood for a minimum time, ensuring at the same time that any environmental disruption in the forest is kept at the lowest possible level. In that way, the highest work efficiency is achieved i.e. the highest income per unit of assortment is attained.

Starting from here, the factors that should be determined before the skidding starts are the area and the harvesting volume, which should be optimally skidded uphill and downhill.

In this scientific paper, the following factors were determined mathematically:

⇒ Factor x, which represents the timber volume skidded uphill.

⇒ Factor (1–x), which represents the timber volume skidded downhill.

For the purpose of this research, separate field studies of skidding were made, which include skidding with: animals – horses, adapted agricultural tractor (Ford) equipped with a winch, and mobile cable crane – Kohler. The same work technology for producing assortments was used for all types of skidding. According to this technology, timber assortments were produced directly at the spot where trees had been felled. Most common assortments were firewood with the length of 1 meter and technical wood (logs) with the length of 3 to 6 meters. For the above reasons, field research was carried out to examine the effect of different types of skidding in normal (typical) working conditions in mountainous terrain, namely in the mountains of Plackovica and Kozuf.

The micro-relief is medium developed, crisscrossed by many smaller or bigger watercourses. The gradient of the terrain is 40%. In such conditions, beech tree forest is developed, ass. *Fagetum montanum*. The assortment structure of trees in the researched areas is 60% firewood and 40% technical wood or logs.

2. Model for calculating the coefficient *x* – *Model za izračun koeficijenta* x

The model developed by Akimovski and Nastevski (1987) and by Akimovski (1966), which is studied

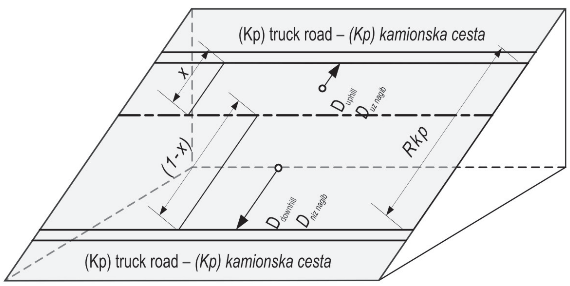

Fig. 1 Felling site between two parallel roads in mountain conditions
Slika 1. *Radilište smješteno između dviju paralelnih cesta u planinskim uvjetima*

here, presents a solution for skidding in mountain conditions when the felling site is situated between two horizontal forest roads. The graphic display of the felling site is shown in Fig. 1.

According to function 1, the factor (x) is calculated by differential calculation of the first statement from the sum of the functions of the time needed for skidding of: logs downhill, logs uphill, firewood downhill, and firewood uphill (function – 2).

$$\frac{DVsum}{Dx} = 0 \tag{1}$$

$$Vsum = Vtp + Vtu + Vop + Vou \tag{2}$$

Legend:

Vsum – total skidding time,

Vtp, Vtu, Vop, Vou – skidding time for logs downhill, logs uphill, firewood downhill, firewood uphill.

In order to adjust the ideal model to the real situations, the adjusted average timber skidding distance could be calculated. The adjusted average timber skidding distance is a real mean distance of skidding from the so-called middle tree, which is situated in the center of the researched area, to the temporary depot. Equations 3 and 4 can be used to calculate the adjusted length of the average timber skidding distance.

$$Lds = \sqrt{\frac{H^2}{ids^2} + H^2} \tag{3}$$

$$Ln = \sqrt{\frac{H^2}{in^2} + H^2} \tag{4}$$

Legend:

Ln – length of the terrain line in meters,

Lds – length of skidding distance in meters,

H – height remainder in meters,

In – terrain gradient,

Ids – gradient of the means of skidding.

The adjusted length can be calculated with formula 5.

$$dkor = \frac{Lds}{Lns} \tag{5}$$

dkor – adjusted length.

The methodology of work is presented in the scientific paper written by Trajanov and Nestorovski (2008).

3. Results of research – *Rezultati istraživanja*

This research is based on the work of the means of skidding researched by Trajanov and Nestorovski (2008), Trajanov and Nestorovski (2009) and Trajanov et all. (2012). In addition, the adjusted length presents a factor that neutralizes the effect of the terrain gradient in relation to determining factor x.

Table 1 Value of the coefficient ***x*** in relation to terrain gradient
Tablica 1. *Vrijednost koeficijenta* x *u odnosu na nagib teren*

Terrain gradient *Nagib terena*	Horse *Konj*	Tractor *Traktor*	Cable crane *Žičara*
%	Coefficient *x* – *Koeficijent* x		
20	0.23	0.36	1.00
30	0.24	0.36	1.00
40	0.24	0.36	1.00
50	0.25	0.36	1.00
60	0.26	0.36	1.00
70	0.26	0.36	1.00

Table 1 shows that the gradient presents a factor not influencing the value of the factor x. The amount of the used volume of wood has an insignificant influence on the factor x, and therefore it is not the subject of research in this paper.

3.1 Coefficient *xa* for horse skidding – *Koeficijent* xa *za privlačenje konjima*

The coefficient *xa* is a part (fraction) of the distance between truck roads (Rkp) that provide wood, which should be optimally skidded uphill by horse skidding. The coefficient (1–*xa*) is a part (fraction) of the distance

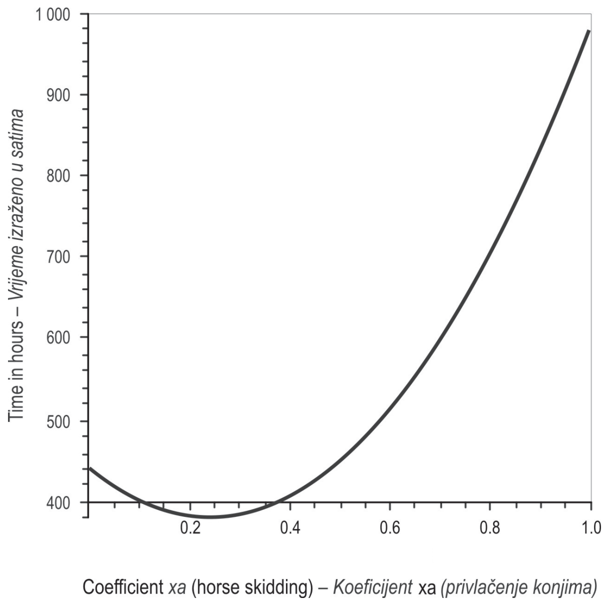

Fig. 2 Value of the coefficient *xa* in relation to the time needed for skidding the wood volume of 300 m^3/ha

Slika 2. *Vrijednost koeficijenta* xa *u odnosu na vrijeme koje je potrebno za privlačenje 300 m^3/ha drva*

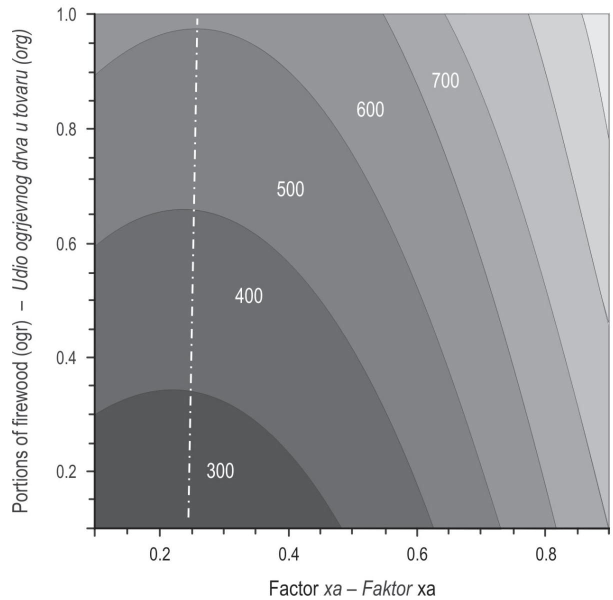

Fig. 3 Time (hours) needed for skidding the wood volume of 300 m^3/ha in relation to factor *xa* and different portions of firewood (ogr)

Slika 3. *Vrijeme (sati) potrebno za privlačenje 300 m^3/ha drva u odnosu na faktor* xa *i različite udjele ogrjevnoga drva u tovaru (ogr)*

between truck forest roads (Rkp) that provide wood, which should be optimally skidded downhill by horse skidding.

With differential calculation, i.e. by calculating the first statement of *xa* from the total skidding time, the factor *xa* = 0.24 has been determined. This means that the work would be done optimally if 24% of the area, including the volume of wood that gravitates towards the higher road, were skidded uphill, whereas the remaining area of 76% were skidded towards the lower road i.e. downhill. According to this proportion, it can be logically concluded that the horse engaged in uphill skidding would not perform well. The values of *xa* in relation to the time needed for skidding (hours) of the assumed wood volume of 300 m^3/ha is graphically presented in Fig. 2.

To determine the relation and the influence of the factor *xa*, a two-dimensional diagram with zone display has been used. In the diagram, the zone is the area in which the influence of two factors has a value within the range of the zone itself. This type of diagram has been used as a display, because in practice the truck forest roads are not ideally parallel, and the terrain itself is not ideally flat, thus one cannot talk about demarcation of an area for skidding uphill or downhill.

Fig. 3 presents the relation of factor *xa* to the assortment structure of wood volume, i.e. the portion of firewood in the total volume of wood. With a deviation of the optimal factor *xa* = 0.24, the time needed for skidding wood assortments increases. In the same way, with the increase of the portion of firewood in the

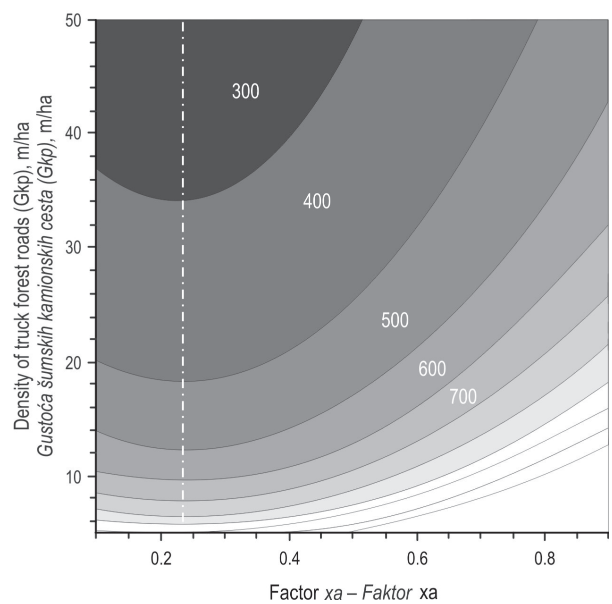

Fig. 4 Time (hours) needed for skidding the wood volume of 300 m^3/ha in relation to factor *xa* with different density of forest roads (Gkp)

Slika 4. *Vrijeme (sati) potrebno za privlačenje 300 m^3/ha drva u odnosu na faktor* xa *i različitu gustoću šumskih cesta (Gkp)* total volume of wood, the time needed for skidding also increases.

Fig. 4 presents the relation of factor *xa* to the density of forest roads in an area unit. With a deviation from the optimal factor *xa* = 0.24, the time needed for skidding timber assortments is increased. When the density of truck forest roads (Gkp) is increased, the time needed for skidding is reduced.

The results of this research apply to the standard assortment method, in which the assortments are processed on the spot: the wood is cut, and from there the process of horse skidding begins. The horses belong to the category of medium-heavy trained horses.

3.2 Coefficient *xt* for skidding with a tractor equipped with winch – *Koeficijent* xt *za privlačenje traktorom opremljenim vitlom*

In the research of tractor skidding, the results refer to the preparation of the load, skidding made on skid trails, and unloading of assortments at the roadside landing as stated by Angelov (1973). The extraction of the assortments from the place where they are cut to the skid trail, by the comber, is not taken into consideration in the calculations. Coefficient *xt* is a part (fraction) of the distance from the truck forest roads (Rkp), which should be optimally skidded uphill when the skidding is done with a tractor. Coefficient (1–*xt*) is a part (fraction) of the distance from the truck forest roads (Rkp),

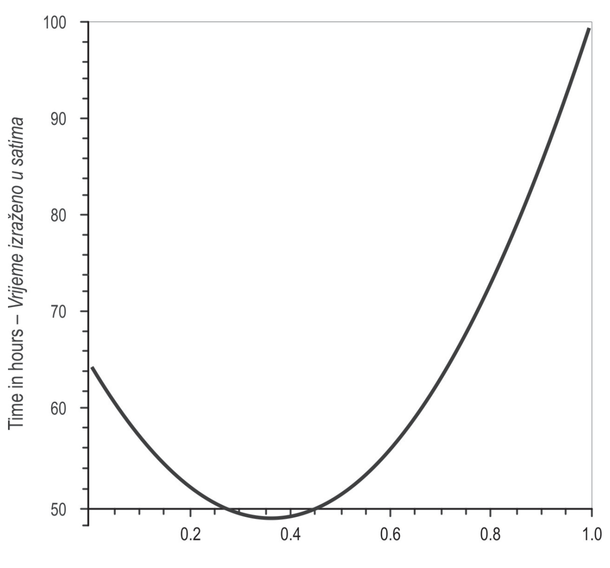

Fig. 5 Values of the coefficient *xt* of tractor skidding in relation to the time needed for skidding the wood volume of 300 m^3/ha

Slika 5. *Vrijednost koeficijenta* xt *pri privlačenju traktorom u odnosu na vrijeme koje je potrebno za privlačenje 300 m^3/ha drva*

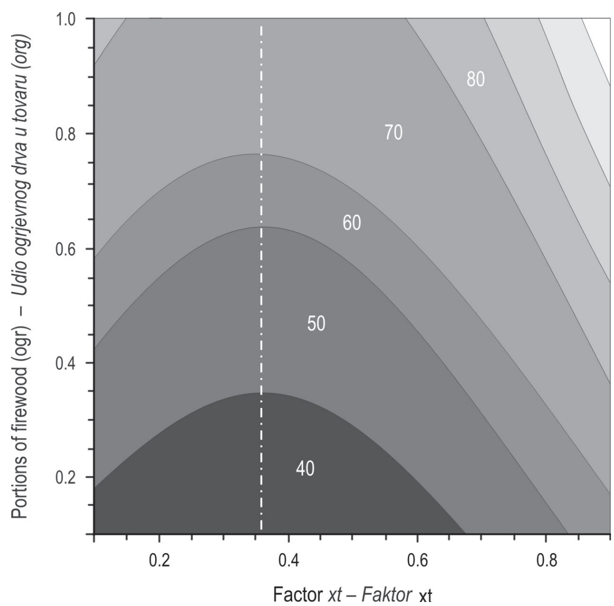

Fig. 6 Time (hours) needed for skidding the wood volume of 300 m^3/ha in relation to factor *xt* and different portions of firewood (ogr)

Slika 6. *Vrijeme (sati) potrebno za privlačenje 300 m^3/ha drva u odnosu na faktor* xt *i različite udjele ogrjevnoga drva u tovaru(ogr)*

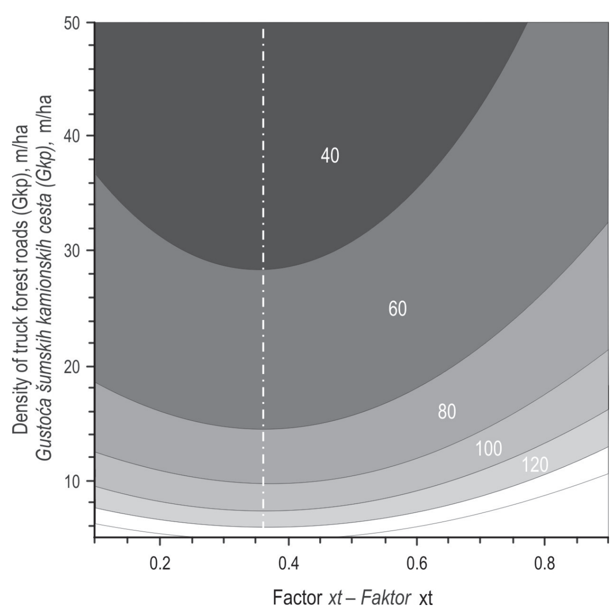

Fig. 7 Time (hours) needed for skidding the wood volume of 300 m^3/ha in relation to factor *xt* with different density of forest roads (Gkp)

Slika 7. *Vrijeme (sati) potrebno za privlačenje 300 m^3/ha drva u odnosu na faktor* xt *i različitu gustoću šumskih cesta (Gkp)*

which should be optimally skidded downhill in fall when the skidding is done with a tractor.

With differential calculation, i.e. by calculating the first statement, the value *xt* = 0.36 has been determined. This means that the skidding would be done optimally if 36% of the wood volume, which gravitates towards the higher road, were skidded uphill, whereas the remaining 64% were skidded towards the lower road i.e. downhill. According to this proportion, it can be logically concluded that the tractor has a better performance when the skidding is done downhill, and that there is no big difference when the skidding is done uphill. The values of *xt* in relation to the time (hours) needed for skidding the wood volume of 300 m^3/ha is graphically presented in Fig. 5.

Fig. 6 shows the relation of factor *xt* to the assortment structure of wood volume, i.e. the portion of firewood in the total volume of wood. With a deviation from the optimal factor *xt* = 0.36, the time needed for skidding wood assortments is increased. The assortment structure also influences the time needed for skidding wood assortments. Thus, with the increase of the portion of firewood in the total volume of wood, the time needed for skidding also increases.

Fig. 7 shows the relation of factor *xt* to the density of the truck forest roads in an area unit. With a deviation from the optimal factor *xt* = 0.36, the time needed for skidding wood assortments increases. When the density of the truck forest roads (Gkp) is increased, the time needed for skidding is reduced.

3.3 Coefficient *xz* for skidding with a mobile cable crane – *Koeficijent* xz *za privlačenje žičarom*

Coefficient *xz* is a part (fraction) of the distance from the truck forest roads (Rkp), which should be optimally skidded uphill when the skidding is done with a cable crane. Coefficient (1–*xz*) is a part (fraction) of the distance from the truck forest roads (Rkp), which should be optimally skidded downhill. According to the model for calculating the coefficient *xz*, it is necessary to determine the time needed for skidding one hectare of wood assortments with a cable crane, when the skidding is done uphill and downhill.

It has been determined by the first calculation that the value of *xz* is 1.00. This means that the skidding would be done optimally if the total volume of wood were skidded uphill. This can lead to the conclusion that the cable crane should be used when the skidding is done uphill. However, this result should be taken with reserve, because the terrain research has shown a certain defect of the cable railway brakes, which led to a relatively slow motion of the load. Construction of the cable railway also takes a lot of time, which again has a negative influence on the final outcome of the work. The curve of the function *xz* in relation to the time needed for skidding the wood volume of 300 m^3/ha has a parabolic shape and is shown in Fig. 8.

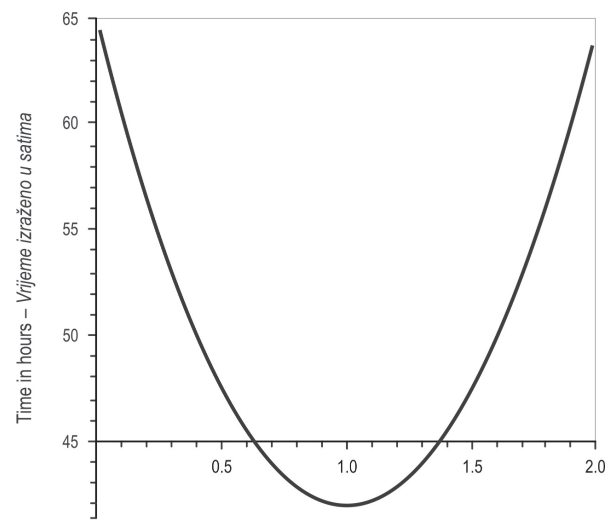

Fig. 8 The value of coefficient *xz* for skidding with a cable crane in relation to the time needed for skidding the wood volume of 300 m^3/ha

Slika 8. *Vrijednost koeficijenta* xz *pri privlačenju žičarom u odnosu na vrijeme koje je potrebno za privlačenje 300 m^3/ha drva*

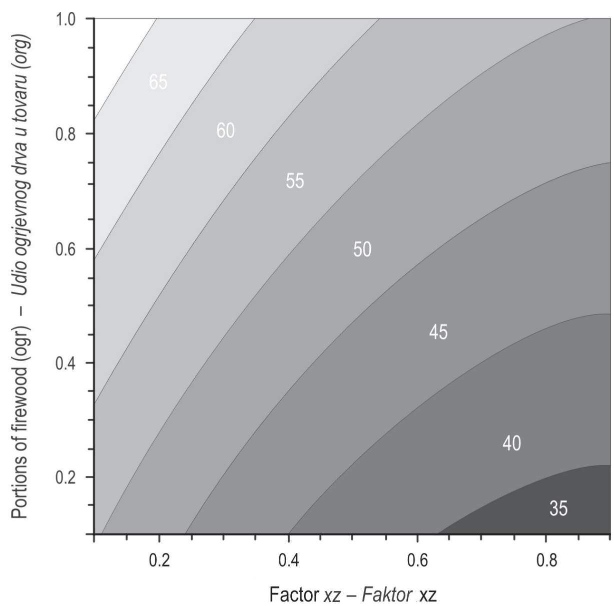

Fig. 9 Time (hours) needed for skidding the wood volume of 300 m^3/ha in relation to factor *xz* and different portions of firewood (ogr)

Slika 9. *Vrijeme (sati) potrebno za privlačenje 300 m^3/ha drva u odnosu na faktor* xz *i različite udjele ogrjevnoga drva u tovaru (ogr)*

Fig. 9 shows the relation of factor *xz* to the assortment structure of wood volume, i.e. the portion of firewood in the total volume of wood. The diagram

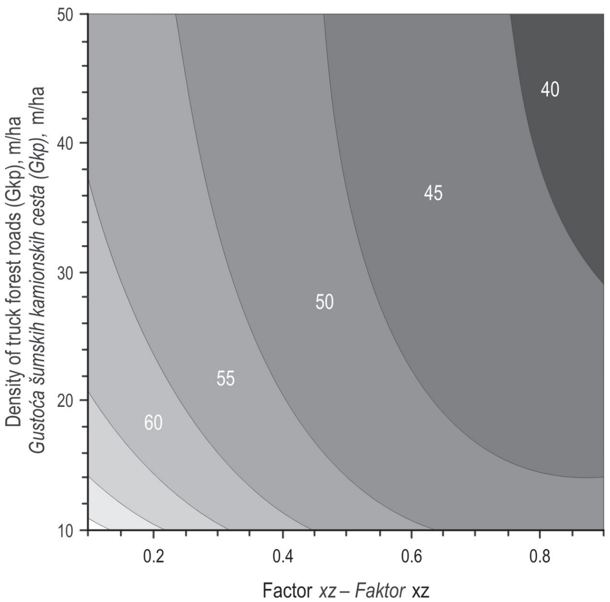

Fig. 10 Time (hours) needed for skidding the wood volume of 300 m^3/ha in relation to factor *xz* with different density of truck forest roads (Gkp)

Slika 10. *Vrijeme (sati) potrebno za privlačenje 300 m^3/ha drva u odnosu na faktor* xz *i različitu gustoću šumskih cesta (Gkp)*

shows that with a deviation from the optimal factor *xz* = 1.00, the time needed for skidding wood assortments increases. The assortment structure also influences the time needed for skidding wood assortments. Thus, with the increase of the portion of firewood in the total volume of wood, the time needed for skidding also increases.

Fig. 10 shows the relation of factor *xz* to the density of the truck forest roads in an area unit. With a deviation from the optimal factor *xz* = 1.00, the time needed for skidding of wood assortments increases. When the density of truck roads (Gkp) is increased, the time needed for skidding is reduced.

4. Discussion and conclusions – *Rasprava i zaključci*

There is no general solution to the problem of skidding wood assortments uphill or downhill. One of the reasons are the many parameters with changeable character that influence the time of uphill and downhill skidding.

When the skidding is done with animals – horses, an ideal fraction of the distance from the truck forest roads would be achieved if a fraction of 0.24 were skidded uphill, and if a fraction of 0.76 were skidded downhill.

When the skidding is done with a tractor, an ideal fraction of the distance from the truck forest roads would be achieved if a fraction of 0.34 were skidded uphill, and if a fraction of 0.66 were skidded downhill.

Considering the bad performance when the skidding is done downhill with a cable crane, the ideal fraction of the distance from the truck forest roads would be achieved if the skidding were done uphill with a fraction of 1.00, i.e. if the total volume of wood were skidded uphill. These results are taken with reserve because the brake mechanism of the researched cable crane was old.

In future, the aim of further studies could be the research of the coefficient *x* for horses of different size and strength, tractors and cable cranes from different manufacturers and with different performances, all in order to make the findings more complete and applicable.

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Sažetak

Optimizacija udaljenosti privlačenja u planinskim uvjetima s različitim sredstvima rada

U šumarskoj praksi tijekom pridobivanja drva postoji mnogo različitih situacija u radnom procesu privlačenja drvnih sortimenata s kojima se postupa individualno ovisno o okolnostima radnoga okoliša te same metode i tehnologije rada.

Osnovni je cilj istraživanja, izložen u ovom znanstvenom radu, pružiti model za izračun optimalne udaljenosti privlačenja drvnih sortimenata uzbrdo ili nizbrdo u planinskim uvjetima. Područja istraživanja (radilišta) na kojima je drvo smještena su između dviju etažno (horizontalne po slojnicama) izvedenih šumskih cesta. Metodološki okvir istraživanja temelji se na radnoj učinkovitosti, odnosno vremenu u kojem je pojedini sortiment privučen (trupac ili ogrjevno drvo), u ovisnosti kada se privlačenje izvodi pomoću (a) životinja, (b) adaptiranoga poljoprivrednoga traktora opremljenoga s vitlom i (c) mobilnom žičarom.

Predočeni rezultati istraživanja smatraju se operativno primjenjivim te mogu šumskim stručnjacima poslužiti pri operativnom planiranju radi donošenja ispravne odluke u privlačenju drvnih sortimenata, odnosno postizanju najpovoljnijih financijskih rezultata rada.

Ključne riječi: privlačenje, drvni sortimenti, optimalna udaljenost, uzbrdo, nizbrdo, trupci i ogrjevno drvo

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